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THE
MANUFACTURE OF LIGHT

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PREFACE

THIS discourse was delivered, as the lecture to working men, to an audience of about 2000 persons, at the York meeting of the British Association on August 4, 1906.

That the author was able so fully to illustrate the lecture by actual experiments was rendered possible only by the co-operation of a number of firms and persons, whose assistance is gratefully acknowledged. The author's thanks are hereby tendered to the Directors and Managers of the York United Gas Light Co., and to Mr. J. W. Hame, engineer of the York Electricity Works; to Messrs. D. Anderson and Co. for the use of a Scott-Snell lamp; to Dr. C. P. Steinmetz of the General Electric Co. for a Magnetite lamp; to the British Westinghouse Co. for the use of two Cooper-Hewitt lamps; to Messrs. Krupka and Jacoby for the use of some Tantalum-lamps; to the Union Electric Co. of Southwark for the loan of an Excello Flame-arc lamp. By the courtesy of Professor W. Wedding, of Berlin, a number of diagrams of his

tests on the distribution of luminous radiation of different sources have been here reproduced.

A special acknowledgment is due to Mr. J. W. Blakey, who arranged for the exhibition of the gas-compressors and the experiments on high-pressure gas-lighting. Finally, the author desires to record the services throughout of his assistant Mr. H. W. Taylor.

S. P. T.

September 1906.

THE MANUFACTURE OF LIGHT

Primitive Sources of Light. — From the earliest dawn of primitive civilisation one of the needs of mankind has been that of artificial light wherewith to lighten the darkness that fell upon him when the sun withdrew his beams. The savage who invented the use of the fire-drill, and by the friction of two pieces of wood procured for himself a spark of fire, discovered thereby not merely the means of warming himself and of cooking his food, but also of providing himself with a luminous flame. Primitive man, while yet a mere cave-dweller, discovered that animal fats and oils would burn, and putting a bit of dry wood or a wisp of grass into a shell or a hollow skull filled with oil, constructed a simple lamp. Amongst the relics of Egyptian tombs or the excavations of Pompeii are found domestic lamps of earthenware or of bronze. Rudely hollowed stones were used by the Northmen. In the museums of Roman remains are to be seen the rude lamps of burned clay which served to hold the oil. Fish oils and animal oils were the sole supply. The blubber of the sperm whale was sought for

in an industry which flourished for several centuries, and made prosperous the seaports of Whitby and Hull. Vegetable oils pressed out from seeds, though known to the apothecary, were scarcely used for illuminating purposes till the eighteenth century; while mineral oils procured from shale, or collected from petroleum wells, were unknown till about eighty years ago; and the paraffin oil-lamp is an invention within the lifetime of most of us.

Primitive man also discovered that a piece of dry wood, or a rope of grass dipped into melted fat, would make an excellent torch; and by dipping a dried rush into molten tallow he procured for himself in small portable form a candle. To substitute a woven wick, and to devise means of casting tallow or wax around the wick in a mould, were improvements devised a little more than a hundred years ago. If we were to go back to the days of good Queen Bess we should find that the means of lighting either hovel or palace were primitive in the extreme. In the guttering of the rushlights and the splutter and smell of the lamps fed with animal oil we should scarcely rejoice.

Invention of Gas-lighting. — Early in the nineteenth century came a great scientific stride forward in the invention of coal gas. In 1802 Murdoch lit the Soho Works with gas distilled in iron retorts; and in 1803 and 1804 Winsor exhibited at the Lyceum in London a system of gas-distribution, and patented a method of purifying the gas and saving the residual products tar and ammonia. In 1808 Murdoch received the Rumford medal of the Royal Society for this application of science to industry.

In 1810 the Gas-light and Coke Co. was incorporated¹ to light the streets of London.

It was several years later that gas-lighting was begun on the continent of Europe.

Invention of Electric-lighting. — If the application of science to industry in the manufacture of illuminating gas was of British origin, no less truly British was the origin of lighting by electricity. Humphry Davy in 1801 or 1802 showed the arc light between carbon poles in the theatre of the Royal Institution, using a battery of 150 pairs of plates; and thirty years later Faraday invented the principle of the dynamos by which the requisite currents could be generated mechanically.²

¹ In view of recent legislation as to electric-supply companies, it is of interest to note the conditions imposed in 1810 on the pioneer Gas Company. They are stated as follows in Accum's *Treatise on Gas-light*, fourth edition, 1818, p. 44 :—

“The power and authorities granted to this corporate body are very restricted and moderate. The individuals composing it have no exclusive privilege; their charter does not prevent other persons from entering into competition with them. Their operations are confined to the metropolis, where they are bound to furnish not only a stronger and better light to such streets and parishes as chuse to be lighted with gas, but also at a cheaper price than shall be paid for lighting the said streets with oil in the usual manner. The corporation is not permitted to traffic in machinery for manufacturing or conveying the gas into private houses, their capital or joint stock is limited to £200,000, and his Majesty has the power of declaring the gas-light charter void if the company fail to fulfil the terms of it.”

² It is true that improvements in both carbons and in generating machines were made in France as well as in England. But the first mechanical arc lamp was that of Staite in 1847; and while batteries were used for the electric-lighting of London Bridge in 1863, on the occasion of the marriage of King Edward VII., then Prince of Wales, dynamos were employed when electric-lighting was introduced in the seventies into lighthouses and into the navy.

As for electric glow-lamps, Grove lit the London Institution in 1847 with little lamps having platinum-wire filaments; and Swan's experimental carbon wire lamp of 1879 was the precursor of all the glow-lamps of to-day.

That an electric spark or discharge could produce light goes back far beyond Davy's time, since electric sparks were first observed about 1670 by Otto Guericke, and Hawkesbee in 1706 observed that an electric discharge sent through a vacuous globe caused it to be filled with a soft, luminous glow. But Bishop Watson, using an inverted U-shaped tube on the plan devised by Lord Charles Cavendish for a double barometer, produced a most beautiful arch of lambent flame. The source was, of course, an old-fashioned friction-machine, for the date was 1746 (*Phil. Trans.* xlvii.); but if we now repeat the experiment and apply a current from a modern electric-supply we get a fine vacuum lamp. It was not until the middle of the nineteenth century that Dr. Geissler popularised the vacuum tube, in which the residual gases became luminous under the discharge of the induction coil.

In this very brief enumeration we have gone over the early attempts to manufacture light by flames or by electric-currents.

Let me point out that in all these attempts (save the vacuum tube or vapour lamps) the evolution of the light is the result of *incandescence*. The process that is common to all of them is that something is made very hot, and shines only because it is very hot. That is to say, whether by flames or by electric-currents, that which is primarily manufactured is heat, and the body on which

the heat is concentrated becomes luminous, so that as a secondary effect light is produced.

Incandescence in General.—Now, as a great part of this lecture will deal with *incandescence*, it is worth while to try to understand thoroughly all we can about the matter. *Incandescence is the shining of hot bodies because they are hot.* We all know that if we take any solid thing, such as an iron rod, or a brick, and heat it enough it will become *red hot*, that is, it will emit or radiate out a red light. If you heat it hotter it shines more brightly, and gives out not only more light, but light of a whiter quality. If it is less heated, the light is duller and redder; and if heated insufficiently to make it red hot, it still emits radiations, but they are of an invisible kind, though they can be felt as radiant heat by holding one's hand near the hot object. All hot bodies emit into the space round them these invisible heat-rays, and the hotter they are the more they emit. So that in all cases of lighting by incandescence the incandescent substance sends out a lot of heat as well as some light. As we shall see, one of the scientific problems of the day is to find a sort of lamp which shall give light without heat. All our sources of artificial light are deplorably wasteful. They burn up a lot of gas or oil, or use up an electric-current, and waste the greater part of it in emitting heat-rays that we don't want, and utilise very little of it in generating the light-rays that we do want.

Solid Particles in Incandescence.—We have seen that all solid bodies when heated hot enough become incandescent. The brightness of flame is, as we shall see,

due to there being solid particles in them. If you procure a flame in which there are no solid particles present, it will give very little light indeed—it is practically non-luminous. If, however, into such a flame we introduce a solid refractory substance, such as lime or magnesia, or a wire of some difficultly fusible metal (such as platinum), or scatter into it fine solid particles, the solids so introduced shine brightly, though they are no hotter than the flame itself. You all know the pale blue flame of the atmospheric gas-burner, called the Bunsen-burner, after the famous chemist who introduced its use. It gives very little light, but is very hot by reason of the perfection of the combustion of the mixed gas and air. If you stop up the holes where the air is admitted, the flame at once becomes bright and smoky. It is in reality then less hot, since—as the presence of the sooty smoke proves—the gas is only imperfectly burned; but it is brighter, because now the minute particles of solid soot in passing up through the flame get heated red hot, or white hot, and shine. Admit the air to the holes in the burner and the flame at once resumes its non-luminous state. But that it is hotter than the luminous flame is proved by the circumstance that the non-luminous flame will melt certain substances—for example, very thin platinum wire—which the luminous flame is incapable of melting.

Everybody will have observed that the flame of an ordinary candle or of an ordinary gas-jet is not all of uniform brightness; there is always a bluish and nearly non-luminous part at the bottom, below the bright part. In this non-luminous part the air from below combines freely with the hydrogen (the lighter constituent of the

hydrocarbon vapour) and heats the inner part of the flame. From the researches on flames of Professor Smithells of Leeds—the principal authority on the property of flames—it is known that a flat gas-flame consists of two flat burning surfaces with a cooler layer of gas in between them. Fig. 1 represents a batwing gas-flame; at the side are marked the temperatures which were found in Professor Smithells' experiments to exist at the various

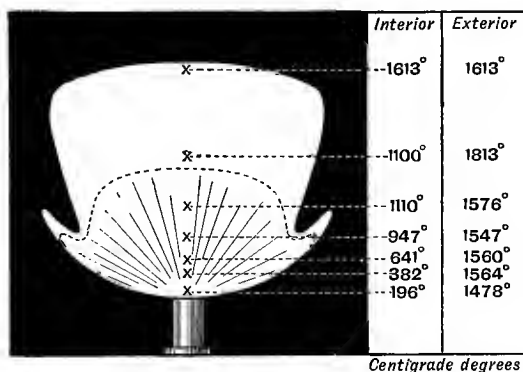


Fig. 1.—TEMPERATURES IN GAS FLAME (SMITHELLS).

points indicated. The brightness of the upper part of the gas-flame is due to the particles of carbon formed in the lower part.

When once it was recognised that the brightness of flames was due to radiation from solid matter, it was an obvious suggestion to try to get more light from gas by burning it with the hottest sort of flame—the non-luminous one, and then inserting in the flame a network of fine wire. In fact thirty years ago mantles of wire-

gauze were tried. The town of Nantes was lit with such burners. But they were not successful, being too perishable.

In the delightful lectures of Faraday on the Chemistry of the Candle a number of simple experiments are described about the production of flame: how the melted wax or tallow rising in the wick is distilled into gas which burns and forms the flame. Every flame is, in fact, a gas-flame—the lower part of the flame and the wick acting as a sort of miniature gas-factory wherein tallow or wax is distilled in place of coal. We may now add to this that every luminous flame also resembles the incandescent gas-burner, for though it has no “mantle” hung in it to be heated, it has solid particles in it to emit the light. The lime-light is an example of the principle of incandescence; for the oxyhydrogen blow-pipe flame used in it is non-luminous, while the piece of lime against which it plays becomes brilliantly white-hot.

Incandescence by Electricity.—Turning to incandescence by electricity, we may remember that whenever an electric-current is forced to flow through a resistant conductor—one made of a resistant material, or a wire of a relatively thin section—the energy expended on forcing the current through is transformed into heat, and this heat is evolved at the place where the current meets with the resistance. If a chain be made of alternate links (well joined together) of iron and copper wire, and an electric-current is sent through it, the iron links will become red hot, because they resist more than the copper links. Combustion has nothing to do with this

electric-heating. The thin carbon wires inside our ordinary glow-lamps are not consumed. They are simply heated from within by the current that is being forced through the highly-resistant carbon thread; and they shine simply because they are hot. In order that they shall not burn away, the air is pumped out of the glass globes in which they are enclosed. In the arc-lamp two stout pencils of carbon, joined by wires to the two electric-supply mains, are made to touch one another for an instant, and then are parted asunder to about $\frac{1}{8}$ -inch. The current forms a sort of flame—called *the arc*—between the carbon tips, and the tips, particularly the tip of the positive pencil, become white hot. The arc is an intensely hot flame; but it is not a flame that will burn of itself. It only burns so long as electric-energy is pumped into it. If the supply of electric-current is cut off the arc goes out at once. The tips of the carbons give light by incandescence, that is to say, they shine because they are hot. In one sense the arc-lamp and the glow-lamp are not really electric-lights, but heat-lights. In them we produce electrically an intense heat, and then the carbons shine simply because they are hot. The arc can be formed in air, or in an atmosphere of inert gas, or even under water, though then it is very unstable. When formed in the air, as in ordinary open arc-lamps, there is some combustion; for the carbon tips slowly burn away. But this combustion adds nothing to the light.

Luminescence.—So far we have been dealing with the manufacture of light by incandescence, in which the light is a consequence of heating. The question arises,

Is there no other way of manufacturing light without heat? There are certainly some examples to be found in nature in which light is produced without heat. They are mostly feeble, but they exist. There is first the class of phenomena called by the name of *Phosphorescence*. Decaying timber and putrescent fish are often observed to shine faintly in the dark. The sea in summer is often phosphorescent at night, every stroke of the oar sending out ripples that seem alive with innumerable points of pale blue light. There is the glow-worm with its exquisite little pale blue gleam, and, less frequently, the fire-fly with its tiny star of light. These are all cold lights. Then there is the artificial pale light emitted in the dark by a stick of damp phosphorus—an example of a slow chemical reaction. To these we must add the class of artificial preparations—of which Balmain's luminous paint is the best known—that have the property of shining in the dark for hours, after having been shone upon by daylight. This category of cold lights has been vastly increased in recent years by the discoveries of Sir William Crookes and others, of the possibility of making substances shine in the dark by exposing them to the special kinds of radiation known as *kathode-rays* and their allies, excited by electric discharges in vacuous tubes. Thus these kathode-rays falling on rubies make them shine with an intense crimson light as if red-hot—yet they are quite cold. In the kathode beam a diamond shines as a brilliant white star; and the earthy oxides, alumina, yttria, etc., glow with strange gleams. We require a name to include all these cases of light without heat. The name that has been given is *Luminescence*.

The problem before us is the manufacture of light ; and we now realize that there are two different ways of manufacturing it : one direct, the other indirect. In the direct process, *Luminescence*, energy of some other kind is directly transformed into light. In the indirect process, *Incandescence*, we use either the energy of fuel or that of the electric-current (itself generated from fuel indirectly) to manufacture heat ; and the hot substance gives out in reality most of its energy as invisible radiant heat, and very little of its energy as visible light. It has been shown that all our ordinary lamps waste in invisible radiations—that is, in heat—over 99 per cent of the energy supplied to them, and turn less than 1 per cent of their energy as light. Think, then, of the importance of the problem before us. That man is said to be a benefactor to his race who will make two blades of grass grow where but one grew before. But in the manufacture of light there is a vastly wider margin. He who will invent a lamp giving light without heat will make all his lamps a hundred times brighter than lamps now are, or will make them as bright as they now are while saving 99 per cent of the energy that they now require.

Luminous Efficiency. — You may well seem incredulous of such statements as that all our ordinary lamps, electric as well as gas and oil, waste over 99 per cent of their energy on making heat. You did not imagine¹ that their efficiency was so low as 1 per cent.

¹ The term *luminous efficiency* is used to denote the percentage borne by the energy of such rays as fall within the luminous range, in the spectrum, to the total energy emitted. There is some dispute about this, probably arising from the different apparatus used by

But there can be no doubt about it. If science be measurement, let us try to understand how such measurements are made.

As a beginning let us get some simple notions as to how the brightness of lights is measured.

Photometry.—Though the eye may be able to say of two lights that one is brighter than the other, yet it is quite incapable of precision in judging how many times one light is brighter than another. But a very simple apparatus will enable us to form a notion on the principles that are used in measuring the relative quantities of light sent out by different lamps. Firstly, we must have some standard to go by. For many years the legal standard in this country was the so-called *standard candle*, being a candle of spermaceti wax, six to the pound, burning 120 grains per hour. But the Metropolitan Gas different observers. A good many determinations have been published formerly in which various lamps are credited with much higher efficiencies. Thus in Professor Fleming's work on Electric Lamps the efficiencies of several lamps are given at about 3 per cent; while one is credited with an efficiency of 15 per cent. In this lecture the more recent figures of Professor W. Wedding of Berlin have been followed. He used a special bolometer provided with means for discriminating between the energy of the visible and that of the invisible rays. He finds no source of light except the flaming arc to have a luminous efficiency as high as 1 per cent. On the other hand, C. E. Mendenhall finds the luminous efficiency of an ordinary glow-lamp to be about 2.6 per cent, which, according to him, would correspond to a temperature of 2150° (absolute) if the filament acts as a black body. The term needs more exact definition, since it is conceivable that two different sources might spend equal fractions of their energy upon luminous rays, and yet, if one of them radiated mainly light in the middle of the visible spectrum, whilst the other radiated much red and blue as well as yellow and green, the former would have a much higher luminosity.

referees have instead adopted as their official standard a light ten times as bright and much more constant, called the Vernon Harcourt 10 candle-power Pentane Lamp. All flame standards¹ are open to certain objections; and it is quite probable that shortly a special electric glow-lamp² of 10 candle-power will be adopted instead.

The oldest plan of comparing the light of two candles or lamps was to set them to shine upon two pieces of white paper side by side, with an opaque partition between, so that each light shone on one of the white surfaces only; and then the candles were moved until, judging by eye, the brightness of the illuminated surfaces was equal. To get such equality the brighter source must be put farther away from the white surface. Thus if a candle and a more powerful oil-lamp were being compared, if the candle is set 1 foot away from the white surface, the oil-lamp may need to be set at a distance of

¹ Flames are unsuitable as standards because the emission by them of light is dependent on so many different circumstances, the temperature and pressure of the surrounding air, and the amount of water-vapour present, as well as the purity of the substance burnt, and the conditions under which the substance is supplied. In Germany the standard flame is the Hefner Lamp in which amyl acetate is burned, the flame being regulated to a precise height. The light of this standard flame is called "one Hefner candle" and is equal to 0.88 standard British candle. A serious objection to the Hefner candle is its decidedly red colour.

² See Professor Fleming, F.R.S., "On the Photometry of Electric-Lamps," *Journal of Proceedings of the Institution of Electrical Engineers*, xxxii. p. 119, Dec. 1903. Fleming's lamp derives its standard quality by being always used at a rather low incandescence, and by being enclosed in a rather large bulb. But its light is also of a rather unduly red quality.

3, 4, or 5 feet away to give an equal illumination. Now if we may regard the candle and the lamp as being points of light, the well-known law of point-action holds good, namely, that the effect of that which emanates from the point varies inversely as the square of the distance. So after adjusting to equality we make the calculation by squaring the distance. Thus if the candle at 1 foot away is balanced by the oil-lamp at 3 feet away, we know that the oil-lamp will be 3×3 times, that is, 9 times as bright as the candle, that is, it is of 9 candle-power. If we had had to put it 4 feet away to get equality of illumination, we should know that it was of 4×4 , that is, 16 candle-power.

Another simple way of comparing together the brightness of two sources was to set up a rod in front of a white surface, and let the two lights cast two shadows. The stronger light casts the darker shadow. So again the stronger source must be moved away until the shadows are equally dark, and the calculation made as before.

The Photometer.—Any such apparatus for measuring the relative brightness of two lights is called a *Photometer*, and most modern photometers are pieces of apparatus¹ of great precision.

In order to demonstrate the measurement of lights to a large audience I have recourse to a novel sort of photometer (Figs. 2 and 3). Along the top of the table before

¹ The principal sorts of photometers are those of Foucault, Bunsen, Lethaby, L. Weber, Joly, Swan, and Lummer-Brodhun. The last-named is an instrument of precision superseding the Bunsen grease-spot photometer. For comparison of lights of different colours the "flicker" photometers of Rood or of Simmance-Abady are preferred.

me lies a narrow bench of wood about 30 feet in length, along which I can slide the lights to be compared. The standard light S_1 is placed on end of this bench; the light S_2 , to be measured, is set on the beam toward the other end. Between them stand two pieces of mirror

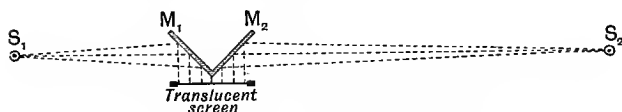


Fig. 2.—DIAGRAM OF SIMPLE PHOTOMETER.

glass, M_1 and M_2 , each set at 45° , so that the beams of light which come along the bench from the right and from the left are both reflected forward toward my audience. After being thus reflected forward they are received on a piece of ground glass (or other dull translucent surface, such as a piece of tracing paper), where



Fig. 3.—GENERAL VIEW OF SIMPLE PHOTOMETER.

you see, therefore, two rectangular patches of light side by side. One of these is due to the beam from the standard source, the other from the lamp that is to be compared with it. Now as this is rather a large hall we must work with a fairly large unit of light, so I take 10 candles mounted on a board and place them on the left side, and set them at such a distance that they would balance 1 candle placed at 1 foot on the right side.

The distance at which they have to be placed is marked "10" on the scale along the table.

Keeping these 10 candles in their place I take an ordinary paraffin oil-lamp and put it on the other side. If it happened to be exactly of 10 candle-power, we should get balance when it was at an equal distance on the other side. But it happens to be a stronger light, so to get balance I push it along the bench until balance is obtained, and then reading off the scale we find it to be about 16 candles. The scale divisions do not, you will notice, come at equal distances apart. For, according to the law of squares, a light which balances at double distance is 2×2 (that is, 4) times as bright, so that the place for 40 on the scale is just twice as far along as the place for 10, and the place for 90 will be 3 times as far along, and so forth. The number of feet along will be proportional to the square root of the candle-power. So to balance 1 candle at 1 foot we may have 4 candles at 2 feet, 9 candles at 3 feet, 16 candles at 4 feet, or going to higher numbers, 36 candles at 6 feet, 100 candles at 10 feet, 400 candles at 20 feet.

Inequality of Distribution.—When once we have got a means of measuring the brightness of lights we soon discover that the amount of light shed by a lamp is not equal in different directions. Some lamps send more light downwards than upwards, others more upward than downward. A flat flame like that of a paraffin-lamp with a flat wick sends out rather less light in the edge-ways direction than in any other. For factory lighting the lamps are fixed overhead and are required to send the light chiefly downwards. For street lighting a lamp

is desired that sends out most of its light sideways ; for we do not want the pavement immediately beneath to be brilliantly lit, while the spaces between the lamps are in comparative darkness. Some of the results of measurements of lamps by specially arranged photometers are shown in the diagrams which follow and

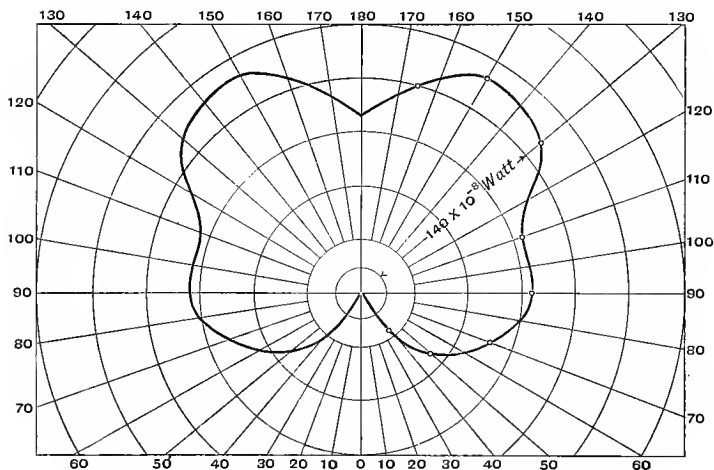


Fig. 4.—DISTRIBUTION OF LUMINOUS RAYS OF PARAFFIN-LAMP (WEDDING).

which are due to Professor Wedding. In these the amount of light at different angles above and below the horizontal are plotted out in radial directions, giving a curve of distribution.

Fig. 4 shows the unequal distribution of a paraffin-lamp flame. It gave about 13 candles horizontally, but at 45° downwards it gave only about 7 ; while at 45° above horizontal, or 135° from the downward direction,

it gave nearly 22 candle-power. Straight down it gave no light, owing to the shadow of the oil vessel. The mean of the candle-power in every direction was 11.6.

Fig. 5 gives the distribution of light from an inverted gas-mantle. It gave very nearly 40 candle-power in

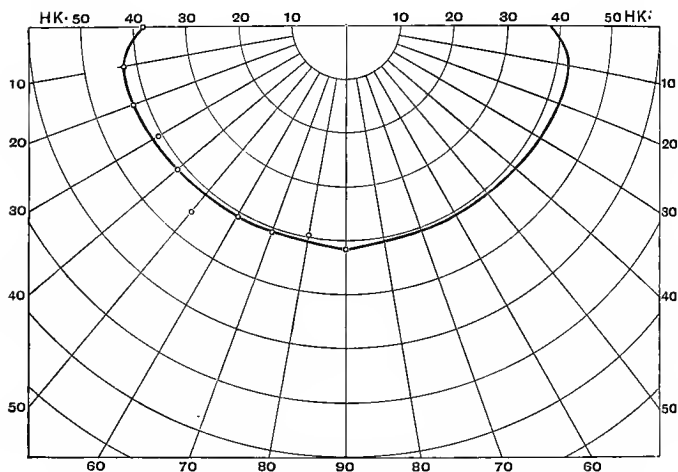


Fig. 5.—DISTRIBUTION OF LUMINOUS RAYS OF INVERTED GAS-MANTLE (WEDDING).

every direction below the horizontal, and threw practically no light above its own level.

Fig. 6 is the curve given by an ordinary Welsbach mantle gas-light. This particular lamp gave 65 candle-power horizontally, 80 candle-power at 20° above horizontal, 43 at 20° below horizontal, about 21 straight up, and none straight down.

Fig. 7 shows the curve of a high-pressure "Millennium"

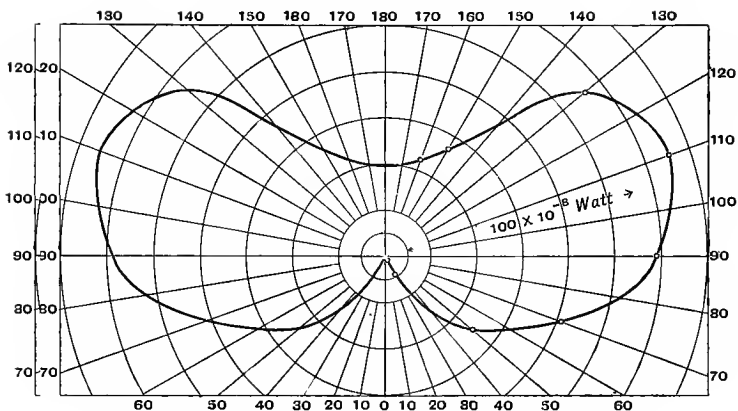


Fig. 6.—DISTRIBUTION OF LUMINOUS RAYS OF WELSBACK MANTLE (WEDDING).

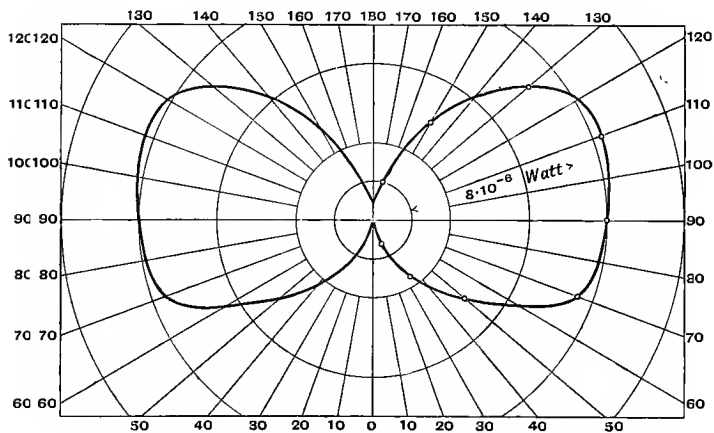


Fig. 7.—DISTRIBUTION OF LUMINOUS RAYS OF "MILLENNIUM" LIGHT; HIGH-PRESSURE GAS, WITH LONG MANTLE (WEDDING).

incandescent gas-light of 1320 candle-power horizontally, about 700 at 45° above the horizontal, and about 560 at 45° below the horizontal. Straight up and straight down it gave very little.

Fig. 8 gives the distribution curve of an ordinary glow-lamp, the horizontal power of which was 16.1

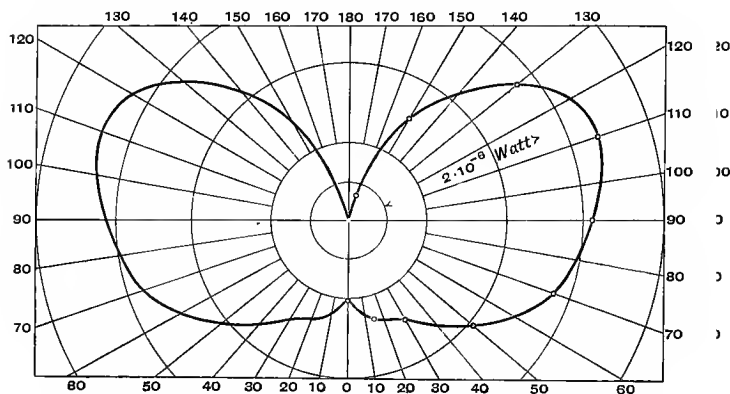


Fig. 8.—DISTRIBUTION OF LUMINOUS RAYS OF ELECTRIC GLOW-LAMP (WEDDING); WATTS, 59.1; MEAN SPHERICAL CANDLE-POWER, 11.26; WATTS PER CANDLE, 5.24.

candles. It gave 5 candles vertically downward, and none vertically upward because of the socket from which it hung.

Fig. 9 is the curve of a Nernst-lamp, giving 162 candle-power horizontally. Vertically up and down its power was zero.

From a study of these diagrams of distribution it is clear that a very imperfect, not to say inaccurate, statement of the power of a lamp would be afforded if we

were merely to measure the candle-power in a horizontal direction. Take, for example, a good gas-jet giving a light equal to 16 candles in the horizontal direction. Upward and downward such a flame sends out much less light than 16 candles, so that the mean of the values in all directions would be less than 16. In fact, the

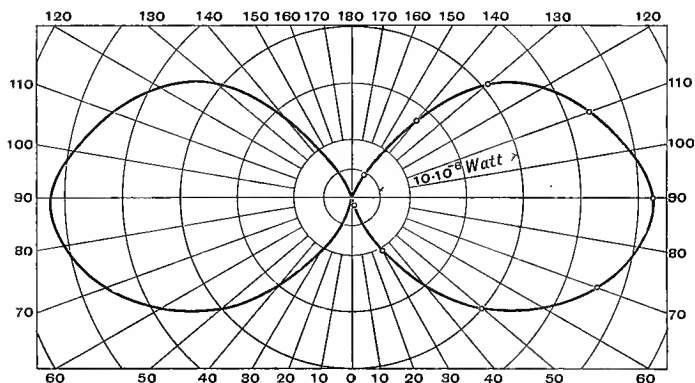


Fig. 9.—DISTRIBUTION OF LUMINOUS RAYS OF NERNST-LAMP WITH VERTICAL FILAMENT (WEDDING); WATTS, 213; MEAN SPHERICAL CANDLE-POWER, 99.4; WATTS PER CANDLE, 2.13.

mean spherical candle-power of such a gas-jet would only be about $13\frac{1}{2}$ candles. In any fair comparison, therefore, between lamps of different kinds, one ought to consider, not the light sent out horizontally only, but the total light in all directions, which is proportional to the mean spherical candle-power;¹ and this can either be measured by a special spherical photometer or “lumen-

¹ See a valuable discussion by Mr. A. Russell in the *Journal of the Institution of Electrical Engineers*, vol. xxxii. p. 631, 1903.

meter," or must be calculated from a number of measurements made at different angles. There is one exception, that of arc-lamps and high-power gas-lamps intended for lighting streets or large rooms. In such cases, as the light thrown upwards is for the most part wasted and lost, it is usual to calculate out the mean effect only of the lower half, that is, the *mean hemispherical candle-power*.

Inequality of Composition. — An equally serious consideration is the composition of the light. Every schoolboy is familiar with the great discovery of Sir Isaac Newton that white light consists in reality of a mixture of lights of all different colours — red, orange, yellow, green, blue, and violet. All the ordinary sources of light, natural and artificial, send out these mixtures of colours. To sort them out from one another we have only to look at the light through a three-cornered glass-prism, or to let a beam of the light pass through such a prism and fall on the ceiling or on the wall. The prism refracts the lights of different colours through different angles, and presents the result to us as a rainbow-coloured patch or *spectrum*. Fig. 10 depicts Newton's fundamental experiment. We now know the reason of all this. Light consists of innumerable little wavelets of extraordinary minuteness. Light of each colour possesses its own particular wave-length; or rather, light of each particular wave-length has its own particular colour. These wave-lengths (the size of the ripples) are so small that they must be measured in millionths of an inch. Thus light that has ripples having a wave-length of 27 to 30 millionths of an inch (70 to 75 millionths of a centimeter) produces a red sensation in the eye, and we

call it red light. Wavelets having a wave-length of about 15 to 16 millionths of an inch (36 to 40 millionths of a centimeter) the sensation of violet. Those of 20 millionths of an inch (50 millionths of a centimeter) the sensation of green. And since all incandescent bodies give out waves of all sorts and sizes, they shine with all the different colours at once, and give out *white* light. We can demonstrate the composition of white light from colours in another way, namely, by taking a glass disc tinted with transparent coloured films, and causing the



Fig. 10.—NEWTON'S FUNDAMENTAL EXPERIMENT OF DECOMPOSITION OF WHITE LIGHT BY A PRISM.

light of the lantern to shine through it, so that the colours are thrown on the screen before you. Then whirl the disc round so as to mix the colours, and at once we get an artificially mixed white light.

But all our lamps are not equally white in the light they give. That is because a true white is not produced unless a proper proportion is preserved between the component colours. If in the mixture there is too much red, the resulting light will be a reddish white. If there is too much green the light will be greenish, and so forth.

For a complete study, then, of the light emitted by any lamp we ought not only to measure its mean or total candle-power, but also to analyse the light to observe its composition. So we must have recourse to Newton's prism and study the *spectrum* of the light of the lamp.

The Teaching of the Spectrum.—Now, what the prism does is this: it throws the largest waves, the red ones, to one end of the spectrum, and the shortest waves, the violet ones, to the other end of the spectrum—the intermediate colours being ranged between in the order of their respective wave-lengths. To produce the spectrum we first pass the light through a narrow slit, focus the beam with a lens, and then interpose the prism to spread out the coloured components.

In this way we now produce on the screen not a picture, but the actual spectrum itself of the white light of an ordinary arc-lamp. To one not familiar with the subject it may seem incredible that these gorgeous colours are actually present in the white light. We are not conscious of them until we thus analyse or sort them out with the prism.

Let me draw your attention to several features: (1) the order of the colours—red at one end, violet at the other; (2) the circumstance that they merge gradually into one another with infinite gradations of tone; (3) that to our eyes the middle part of the spectrum, in the yellowish-green region, is the brightest part; (4) that at the ends the colours fade off into darkness. Now that darkness is not due to absence of rays. There is plenty of radiation in the dark spaces at both ends—only our eyes cannot

see it ; we are blind to the wavelets that are either shorter than the violet ones or longer than the red ones. The proofs that there are these invisible radiations are very simple. A thermometer placed beyond the red end will show that there are dark radiations—which we may call heat-waves—in that region ; and a bit of photographic printing-out paper placed in the region beyond the violet will be darkened, showing that at that end there are some invisible photographic rays.

Spectra of Incandescent Solids and Vapours. —

Now I come to an exceedingly important point. Any ordinary solid body, when heated hot enough to become incandescent, will give a spectrum just like that I have shown, in that it will show all the colours from red to violet in a continuous band. All ordinary solids yield, when they shine, a continuous spectrum. But there are some substances which when heated to incandescence give out a spectrum of a different kind, consisting, not of all the colours, but of only a few particular ones. Think of some musical instrument such as a piano. What would result if we were to strike all the keys at once? A horrid crash—a mere noise—with all the different notes jumbled up together. How different if we strike but one key and produce a pure tone, or only two or three keys and produce a chord ! Now, as I say, there are certain substances which instead of giving us white light—a crash of all different colours jumbled up together—emit a few single pure rays. The coloured lights that are used in fireworks are crude examples. Now remember this, the substances which will thus emit a few selected rays are, for the most part, not solids. Gases and

vapours, if heated hot enough to shine, give out only selected rays. The gas *helium*, discovered by Sir William Ramsay, shines with a pure yellow light; the vapour of *sodium* gives out two rich yellow rays; *hydrogen* shines with four rays, a red, a sea-green, a blue, and a violet ray; the vapour of *silver* with three beautiful green rays; the vapour of *mercury* with some red and some green rays; the vapour of *iron* with several hundreds of rays.

I want, while the prism is in its place, to show you the spectrum of some of these. Inside the lantern there is an arc-lamp, and in the lamp I place a small carbon crucible. In this crucible we will put a pellet of silver, and then cause the arc to play on it. In a moment, such is the intense heat of the arc, the silver will be melted, then it will boil, giving off vapour of boiling silver; and this vapour will be heated to incandescence and will glow with a green light. The prism will analyse the light, and there on the screen you see the characteristic rays in the green part of the spectrum. Into the crucible we will now drop a scrap of zinc, and forthwith you observe the spectrum of the vapour of zinc, with two blue rays and a fine red one. Yet once more we will drop into the crucible a bit of a salt of calcium,—fluor-spar,—and behold the characteristic orange light of the vapour of calcium. We shall come back to the importance of these things presently, but must not forget the difference between the continuous spectrum of ordinary solids and these discontinuous spectra that consist of bands of selected rays, and are the spectra of vapours.

Sensitiveness of the Eye to Radiations of Particular Wave-lengths.—I have already drawn your attention to the circumstance that the ordinary spectrum is brightest in the middle region. The spectrum was made of the white light of the arc; and the light of the arc is manufactured by passing an electric-current between the white-hot tips of the carbons, thus pouring in electric-energy which makes them radiate. If you did not know otherwise you might suppose—and the supposition would be wrong—that the greater luminosity of the yellow-green region was due to a larger amount of energy being expended on manufacturing rays of that colour. But this is not so. The yellow-green in the middle looks indeed brighter than the red at the end of the spectrum, but there is far more of the energy being spent on producing the red rays than in producing the yellow-green. Why then does the yellow-green look brighter? The answer is to be found in the properties of the eye. I have already remarked on the fact that the eye does not see the invisible dark rays that lie beyond the end of the spectrum—it is blind to those rays. And the eye is not so sensitive to those kinds of light that lie near either end of the spectrum as to those in the middle region. Careful experiment has shown that the eye is most sensitive to light that has a wave-length of about 50 millionths of a centimetre (20 millionths of an inch), and is of a green colour. The diagram, Fig. 11, gives the result of the measurements of the late Professor Langley. He found the apparent luminosity, for equal amounts of energy, to be a maximum for light of a wave-length of 53 millionths of a

centimetre. And, as the table shows, if we take the luminosity of this green light as 100, then that of blue is only 62 per cent as great, that of yellow 28, that of orange 14, that of violet 1.6, and that of red 1.2. But you will say the red in the spectrum looks more than 1.2 per cent as bright as the green part. Yes, but remember that these figures are for equal amounts of energy; and as in reality the lamp throws three or four

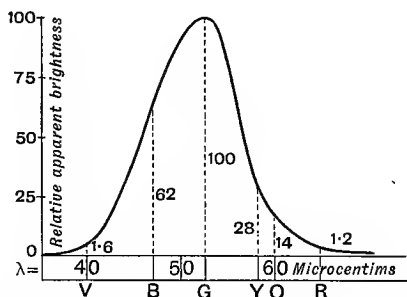


Fig. 11.—LANGLEY'S CURVE OF RELATIVE LUMINOSITY FOR EQUAL AMOUNTS OF RADIATION OF DIFFERENT WAVE-LENGTHS.

times as much energy into the red as it does into the green, the relative luminosity as we see it in the spectrum does not fall for red so low as 1.2 per cent of the green.

While we are on this question of the composition of lights, let us give a moment's attention to some of the results that have been obtained by applying the principles of photometry to the measurement of the amounts of different colours that enter into the composition of the light from different sources. We all know that gas-lights look yellow compared with daylight. What is

there in the composition of these lights to account for this? We do not need to make a separate measurement for every kind of ray all along the spectrum; that would be too endless a task. It suffices to measure the relative brightness for three particular colours, namely, the colours which are respectively nearest to the three primary colour-sensations of the eye. Now the three colour-sensations which are primary¹ to the normal eye are red, green, and blue (a blue inclining toward violet). Hence if we measure the relative amounts for these three colours we can infer the composition for any light of the kind that has a continuous spectrum. The following are some of Sir William Abney's measurements:—

RELATIVE COMPOSITION OF LIGHTS,
recalculated from Abney's COLOUR MEASUREMENT, p. 121.

	Red (C).	Green (E).	Blue (G).
Gas-light . . .	45	43	12
Arc-light . . .	18	36.7	45.3
Sunlight . . .	19.2	37	43.8
Sky-light . . .	9	23	68

¹ If any colour excites but one set of nerve-sensations in the eye it will be called a primary. If it excites two or three sensations it cannot itself correspond to a single primary sensation. Yellow, for instance, excites two sensations, the red and the green: therefore it is not physiologically a primary. Red (of a wave-length 65.2 millionths of a centimetre, and of a quality near the spectrum-line C) is a primary. Green (a rather yellowish green of a wave-length 53.5, and of a quality near the spectrum-line E) is another primary. The third primary is blue-violet (of wave-length 45 near the spectrum-line G).

Gas-light contains less blue than sunlight, while it has a relatively larger percentage of green, and a much larger percentage of red.

Another point of significance in the study of light and its absorption by passing through translucent media, is afforded by Abney's measurements on the absorbing effect of the atmosphere at sunset. Why does the sun look red as he goes down? The atmosphere absorbs

ABSORPTION EFFECT ON SUNLIGHT WHEN OVERHEAD,
calculated from Abney.

Elevation.	Through Atmospheres.	Red (C).	Green (E).	Blue (G).	
90°	1	19.2	37	43.8	= 100 % white
11°.3	5	12.5	12.1	4.4	= 29 % yellow
7°.3	8	1.0	...	...	= 1 % red

a lot of the light, and absorbs the short waves—blue and violet—more than the long ones. A greater thickness of atmosphere as the sun nears the horizon absorbs off not only the violet and blue, but also the green and the yellow. When he is still seven degrees above the horizon—a quarter of an hour before final disappearance—all is absorbed off except 1 per cent, and that unabsorbed residue is red.

Absorption and Emission.—We have not done with the spectrum yet; but the mention of absorption leads us at once to another all-important question, the relation between absorption and emission. Consider what may happen if any radiation, whether of the visible sort or of the invisible heat-waves, falls upon any sub-

stance. There are three things that may befall those rays. (1) If the substance is a polished metal like silver the rays will be *reflected*—thrown off—as from a mirror; you all know that a concave polished metal surface can act as a burning mirror and reflect heat-waves as well as light-waves. (2) If the substance be clear, as glass or water, the rays will be *transmitted*, and come out at the other side. (3) If the substance is dark, opaque, rough, like black cloth or slate, the rays will be *absorbed*; that is, they will neither be turned back nor allowed to go through, but will be stopped, destroyed, killed, absorbed into the substance, and the substance will thereby be warmed. Any black, unpolished, opaque substance exposed to sunlight gets hot, much hotter than either a polished metal substance or a transparent substance. A black hat is much hotter in sunshine than a polished brass helmet. All black bodies absorb. The black soot on the bottom of a kettle helps the kettle to absorb the heat radiating up from the fire.

Now what has this to do with *emission* of light or heat? Simply this: those substances which are good absorbers are found to be also good emitters. Make a substance hot, then if it has a black, opaque, rough surface it will radiate out its heat (and light) into the surrounding space quicker than if it were either polished like silver or clear like glass. Take three glass flasks of equal size; let one be silvered over like a mirror on its outside, let the second be left clear glass, let the third be blackened on the outside. Fill all three with hot water. The one with black surface will be found to cool fastest; because its surface is black it can emit heat-waves better

than either of the others. Now it has been known for many years that the absorbing and emitting powers of bodies are precisely proportional to one another. If we could procure an absolutely black body it would not only absorb all radiation that might fall on it, but it would, at any given temperature, emit all sorts of rays better than any other sort of body black or bright could do. Bright polished bodies are bad emitters. A silver teapot for this reason ought to be kept bright, in order that it shall *not* emit the heat that you want to keep inside it. The pot *ought* to be able to call the kettle black. Kirchhoff showed that this reciprocity between radiating and absorbing power was true for particular rays of the spectrum. Any substance—didymium, for example—which absorbs special rays, will emit special rays of that same wave-length, when raised to incandescence.

Measurement of Emission. — Again, to win a knowledge of the facts we must have recourse to *measurement*. We must know to measure the amount, not of light, but of heat—that is to say, of energy, whether visible or invisible—that is radiated from hot bodies; and we must further be able to find out the sort of waves—that is, the wave-length of the waves—that are being emitted. Sir John Herschel did this roughly in 1802 when he explored the spectrum of sunlight with a thermometer having its bulb blackened. He found, as you already know, that the red waves are hotter than the yellow, green, or blue, and that the hottest waves were invisible in the dark part of the spectrum beyond the end of the red. In the progress of science finer measur-

ing instruments have been invented—the *thermopile*, the *radio-micrometer*, and, lastly, the *bolometer*. Time fails me to describe these. Suffice it to say, that the bolometer, the invention of the deceased physicist Langley, is a beautiful electrical instrument which measures with utmost precision the amount of energy that may fall upon it. It makes no discrimination between visible and invisible radiations, but impartially absorbs them all, and measures the quantity of energy they bring.

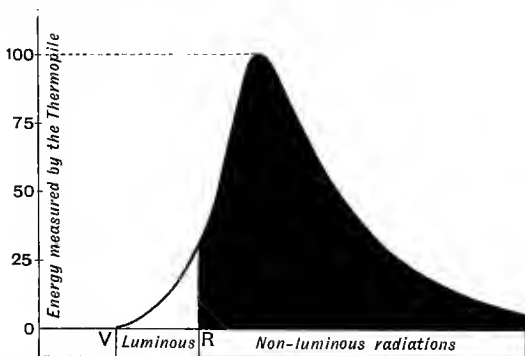


Fig. 12.—TYNDALL'S CURVE OF AMOUNTS OF ENERGY RADIATED IN THE SPECTRUM OF ELECTRIC ARC.

Langley, producing first a spectrum and then exploring the spectrum with his bolometer, was able to show the essential correctness of the earlier experiments of Tyndall, who, using a thermopile, had shown how in the spectrum of the arc-lamp (Fig. 12) the radiation beyond the end of the visible red increases, to quote his own inimitable phrase, into a perfect "Matterhorn of heat." Langley's diagram reproduces in general Tyndall's; but he

also added for comparison a diagram of the distribution of energy in the spectrum of the sun (Fig. 13), from which two things become evident: (i.) that there is

Langley's Curves for One Unit of Heat.

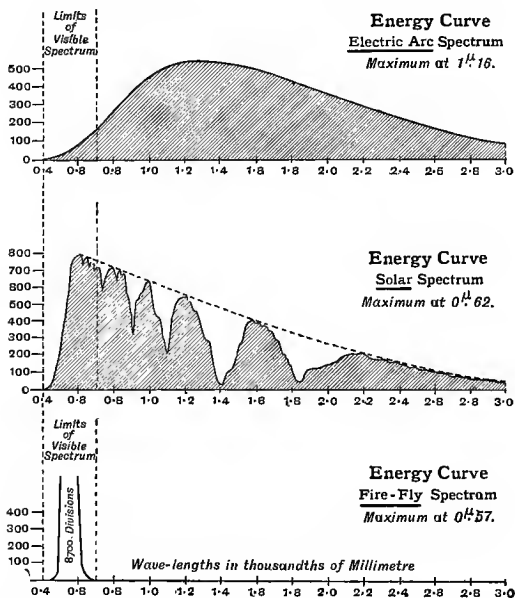


Fig. 13.—LANGLEY'S CURVES OF ENERGY IN THE SPECTRUM FOR ONE UNIT OF HEAT; *a*, ELECTRIC ARC; *b*, SUNLIGHT; *c*, LIGHT OF FIRE-FLY.

irregular absorption in the sun's heat spectrum, indicated by the jagged outline of the curve; (ii.) that while the peak of the curve for the arc is a considerable distance to the right in the dark rays beyond the red, the peak for the sun's energy is within the range of the rays that

are luminous. In other words, while the wave-length for which the energy of the electric carbon arc is a maximum is about 120 millionths of a centimetre, in the sun's spectrum the wave-length for maximum energy is about 55 (or, according to Abbott, just under 50) millionths of a centimetre.

Bad Economy of Ordinary Sources.—When we look at these diagrams, whether Tyndall's or Langley's, we cannot but be struck with the disproportion between the energy wasted on producing dark heat, and that usefully expended on producing light that we can see. In the case of the arc spectrum of Langley the energy wasted on heat is over a hundred times as great as that utilised in giving light. In the sun's spectrum the proportion utilised is much greater; the energy wasted on heat is roughly five times as great as that employed in bringing light. The luminous efficiency of the arc is under 1 per cent, while that of the sun is nearly 20 per cent. The most recent researches on this subject by Professor Wedding¹ have shown the luminous efficiency of ordinary oil-lamps, gas-burners, and electric glow-lamps to be all under one per cent. The process of incandescence, as carried out in all the ordinary sources of light, whether flames or electric-lamps, appears extraordinarily wasteful. When we make a hot body hot enough to shine it gives out far more heat than light. By no process of pure incandescence can we realize the ideal case of getting light without heat. Nature does not work that way, at

¹ W. Wedding, *On the Efficiency and Practical Value of the most usual Sources of Light* [in German], Berlin, 1905. See table on p. 62.

any rate in the emission of radiation from solids. When by heating them we set their molecules vibrating, they emit the longer wave-lengths first, and not until they have been raised to so high a temperature as to emit a large proportion of the longer waves will they emit a measurable amount of the shorter waves that are luminous.

Light of the Fire-fly.—But Langley, if he thus showed how uneconomical are all our ordinary sources of light, also told us in a very remarkable paper¹ published in 1890, that there is in nature another process by which it is possible to produce without heat other than that of the luminous rays themselves. My colleague, Professor Meldola, F.R.S., who is a distinguished naturalist as well as an eminent chemist, once examined with the prism the light of the glow-worm, and found it to be a narrow region principally in the middle part of the spectrum, without any red rays. Professor Young, an American astronomer, similarly examined the light of the American fire-fly, and found it to give a spectrum from the orange end of the red to about half-way down the blue—that is, of rays which, while they are just those that stimulate vision, produce relatively little thermal or actinic effect; “in other words, very little of the energy expended in the flash of the fire-fly is wasted.” This interesting suggestion Langley set himself to test with his delicate bolometer. The result is given graphically in the lowest diagram of Fig. 13, where it appears that the fire-fly emits no measurable amount of dark heat,

¹ “On the Cheapest Form of Light,” by S. P. Langley and F. W. Very, *American Journal of Science*, xl. p. 97. August 1890.

but sends out radiations only within the limits of the visible spectrum. The top of the fire-fly curve could not

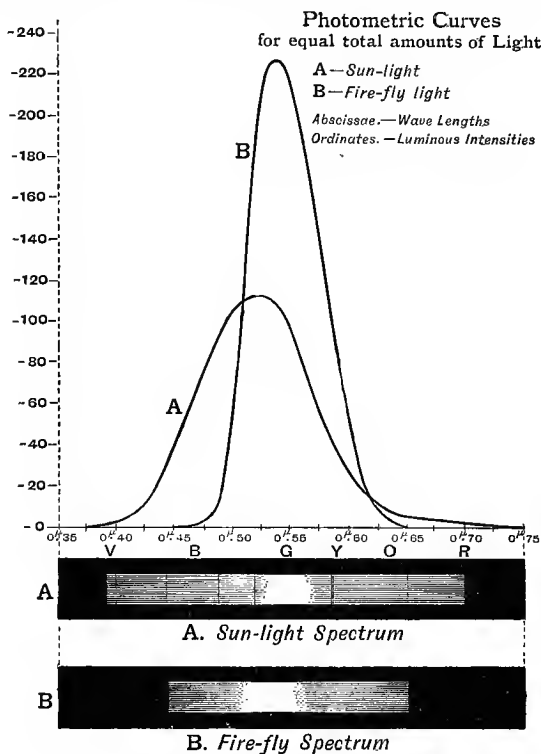


Fig. 14.—COMPARATIVE SPECTRA OF ENERGY FOR EQUAL AMOUNTS OF VISIBLE RADIATION OF SUN AND FIRE-FLY.

be included in the diagram for want of height. Not only so, but the distribution of the rays within the visible spectrum is extraordinarily favourable. Fig. 14 shows

the comparative luminous spectra of sunlight and fire-fly light. Both spectra are bright in the middle, and fade off towards the ends; but the fire-fly spectrum is more concentrated than the sunlight spectrum about the green rays—precisely those to which the eye is most sensitive. The light of the insect is accompanied by approximately only $\frac{1}{400}$ th part of the heat that would 'ordinarily be associated with an equal amount of light if produced by ordinary flames. If only we could expend the energy of our gas, oil, or electricity as economically as the fire-fly expends its energy, we ought to get for the same expenditure four hundred times as much light as we do in fact now get. Clearly the glow-worm and the fire-fly manufacture their light by some quite different process from our crude and inefficient methods. They certainly do not work by incandescence.

The fact that there exists in nature a process so much more economical, impels us to reconsider the method of incandescence to learn more closely how the emission of light depends upon the temperature.

Temperature and Quality of Radiation.—We owe chiefly to German physicists—Wien, Paschen, Lummer, Pringsheim—the careful investigation of the relation between temperature and radiation. As already stated, the best emitter ought to be an absolutely black body. Even lamp-black is not absolutely black, but is slightly a reflector. But Lummer has ingeniously realized an apparatus equivalent to an absolute black body, by using an enclosed cavity blackened on the inside, with a small hole opening into it. If this is heated, the radiations which come out of the hole will be practically the same

as those of an absolutely black body of the same temperature. With this apparatus he has verified a law enunciated by Wien and Paschen, that the wave-length of the dominant radiation is inversely proportional to the absolute temperature. For any given absolute temperature one may calculate the dominant wave-length (in micro-centimetres) by dividing 294,000 by that temperature. This gives us the following relations :—

Absolute Temperature.	Dominant Wave-length.
1000°	294
2000°	147
3000°	98
4000°	73
5000°	59
6000°	49

Fig. 15 gives in a diagram, in which no attempt is made, however, to present the amounts of energy to scale, the way in which, as the temperature is raised, the black body emits more and more radiant energy, and in which while the emission of energy thus rises¹ with the temperature, the position of the peak of the curve shifts from the region of invisible heat-rays toward the region of visible luminous rays. In reality the upper curves ought to

¹ The law was discovered by Stefan that the amount of energy radiated (from a black body) is proportional to the fourth power of the absolute temperature. For the absolute black body, according to the measurements of Kurlbaum, the coefficient of emissivity is 5.32×10^{-12} watt per square centimetre, so that any black body at an absolute temperature of θ radiates to its surroundings with a power of $5.32 \times \theta^4 \times 10^{-12}$ watts.

rise much higher; for the total energy radiated by a black body at 4000° is sixteen times as great as that radiated at 2000° . Looking at this diagram we see that at 2000° (absolute) the dominant wave-length is about 147 millionths of a centimetre, and that by far the greater

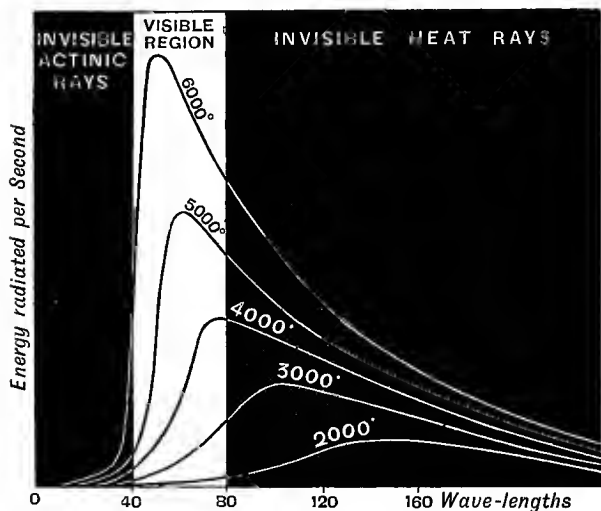


Fig. 15.—ENERGY SPECTRA OF RADIATION OF BLACK BODY AT DIFFERENT TEMPERATURES.

part of the radiation is dark. When the temperature is raised to 3000° there is more dark radiation than before; but the peak has crept to the left, so that the dominant wave-length is now at 98, and the proportion of visible radiations to invisible has greatly increased. Every increase of temperature raises the relative amount of the visible radiation.

In the following Table are given the temperatures and the dominant wave-lengths for a number of sources of radiant energy, on the supposition that they all radiate as an absolute black body would do. The temperature of the Welsbach mantle is probably estimated too high, being inferred from its dominant wave-length.

TEMPERATURES AND DOMINANT WAVE-LENGTH OF
DIFFERENT SOURCES OF RADIATION

	Centigrade.	Absolute.	$\lambda_{\text{dom.}}$
Sun	5880°	6153	50
Carbon Arc	3800°	4073	72
Welsbach Mantle	(?)2027°	2300	128
Nernst Lamp	2027°	2300	128
Platinum melts	1775°	2048	143
Bunsen Flame	1750°	2023	145
Carbon Glow-lamp	1727°	2000	147
Gas Flame	1613°	1886	157
Candle Flame	1577°	1850	159
Gold melts	1250°	1523	195
Silver melts	1090°	1273	230
Water boils	100°	373	790
Ice melts	0°	273	1080

NOTE: Wave-lengths are given in micro-centimetres. Visible radiations lie between $\lambda = 81$ and $\lambda = 36$.

But no actual substance is so good a radiator as the ideal black body, and such a metal as polished platinum, which remains highly reflective even when white hot, ought to be of lower emissive power. And so it was found to be by Lummer. Fig. 16 gives, in correct scale, the energy spectra as measured by Lummer both for the black body and for bright platinum. The highest of the

curves drawn with a full line represents the radiation of the black body at 1646° (absolute), and its dominant

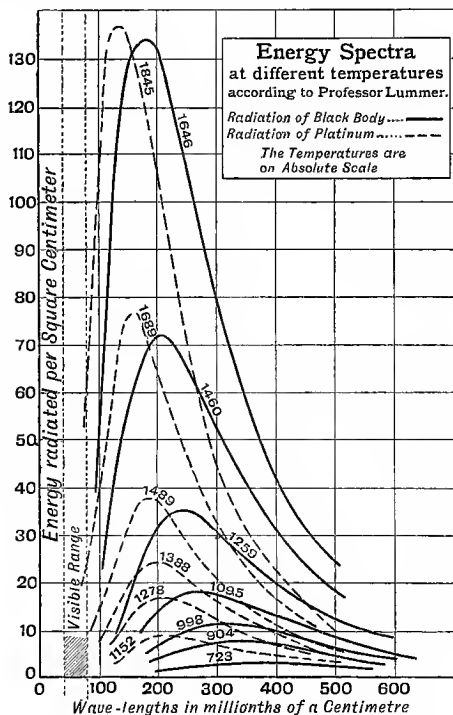


Fig. 16.—LUMMER'S ENERGY SPECTRA AT DIFFERENT TEMPERATURES OF A BLACK BODY AND OF BRIGHT PLATINUM.

wave-length is 180 millionths of a centimetre. There is given—in dotted line—a curve for platinum at nearly the same temperature, viz. 1689° . On comparing these two curves we see that the radiation from the platinum

is much less; the areas under the respective curves represent the totals of energy emitted. *But the peak of the platinum curve is nearer the region of visible rays*, the dominant wave-length being 156 instead of 180. The platinum, though it radiates less energy, will have a larger proportion of visible rays in its radiation; hence bright platinum is a more economical radiator than the black body. It may be far from realizing the ideal of light without heat, but it emits less heat and relatively more light.

Emissivity of the Rare Earths.—The question naturally arises, If polished platinum, which, because of its reflective power, is a bad emitter of heat, is thus a more efficient producer of light than the black body, are there any other bodies which show any special power of emitting rays of the luminous quality? Well, it has long been known—was known even in Tyndall's time—that certain rare earths exhibit when incandescent a remarkable spectrum different from that of ordinary solids. Amongst these earths are the materials known to the chemists as erbia, yttria, didymia, zirconia, thoria, ceria. They are all white substances resembling lime; but whereas lime, when heated to incandescence, gives an ordinary continuous spectrum, these rare earths are observed to give in addition certain bright bands in particular regions of the spectrum. Their spectrum, in fact, is of a mixed type, partly like that of a solid, partly like that of a vapour. Further, it is found that some of these have this property to an exceptional degree when admixed in small quantities with other bodies. For instance, zirconia is very like lime, but if admixed with

a small percentage of yttria gives out far more light than when used alone; the yttria seems to make it emit relatively more yellow and green rays. Also thoria, if mixed with only 1 per cent of ceria, gives out far more light than pure thoria, and the mixture radiates an unusually high proportion of green and yellow in its spectrum. Whatever be the physical explanation¹ of these phenomena, the facts are of utmost importance in their practical bearings.

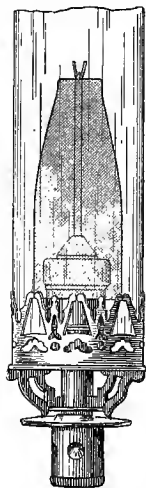


Fig. 17. — INCANDESCENT GAS MANTLE OF AUER VON WELSBACH.

Incandescent Gas-lights.—An enormous stride in gas-lighting was made in 1883, when Dr. Auer von Welsbach introduced the well-known *Welsbach mantle*, which he hung in the non-luminous flame of a Bunsen burner. The merit of his invention consisted mainly in the practical realization of a means for raising to incandescence the rare earths, the special radiating properties of which have just claimed our attention. The modern

¹ Recent research has removed any doubt that might have existed as to the fact that particular solids possess specific emissivities. The similar circumstance that a mixture of 99 per cent of thoria with 1 per cent of ceria emits at the same temperature a brighter light than either pure thoria or pure ceria, has been explained by Professor Rubens. The action does not appear to be chemical, nor is it luminescent: for though in some of the phenomena of luminescence (fluorescence for example), the action appears to depend on the presence of small quantities in dilute liquid or solid solution, the percentages in such cases are far less than of the order of 1 per cent.

process of making the mantle is as follows:—A light fabric of cotton, or, better still, of ramie fibre, is woven or knitted with an open mesh. It is soaked in a chemical solution of the rare earths, dried, and then burned. This leaves a skeleton of white ash, of the same shape as before, but shrunk in size. When hung in the hot flame of an atmospheric burner (Fig. 17) it glows with great brilliancy. The mantles are temporarily hardened for transportation by being treated with collodion. The composition of the rare earths left in the ash is stated to be 99 per cent of thoria, with 1 per cent of ceria. How great an improvement is effected in gas-lighting by this invention is readily understood by reference to the following table:—

LIGHT EMITTED PER CUBIC FOOT OF NORMAL GAS
PER HOUR

		Candle-power per Cubic Foot.
Without mantle.	Union flat-flame jet No. 1	0.85
	" No. 2	1.22
	" No. 3	1.63
	" No. 4	1.74
	" No. 5	1.87
	" No. 6	2.15
	" No. 7	2.44
With mantle.	Standard Argand burner	3.20
	Ordinary Welsbach	11 to 19
	Kern burner	20 to 25
	High-pressure burner	30 to 35

Comparing the case of an ordinary No. 4 flat-flame gas-jet with an ordinary Welsbach burner and mantle, we see that using precisely the same amount of gas the amount of light is increased from 6 to 11 fold. That is to say, the cost of gas-lighting has been reduced to $\frac{1}{6}$ or $\frac{1}{11}$ of its

former cost. There is, of course, the cost of mantles to be set off against the gain ; and it must not be forgotten that the light of the mantles diminishes after they have been for some time in use. By use of Kern burners, which produce a more complete admixture of air and gas, a hotter flame is produced, increasing the output of light. The cause of this gain in brilliancy will be clear from what we have already learned. In the atmospheric burner a higher temperature is reached (namely, about 2023° , absolute) than can be attained in the flat gas flame (about 1613° C. or 1886° , absolute). This higher temperature of itself accounts for something ; but over and above this we have the use of a mantle composed of these rare earths of specific emissivity which radiate out particular groups of rays of the kind to which the eye is sensitive. Do we object to the greenness of the Welsbach light? It is that very greenness which gives them their high illuminating quality.

Researches of Rubens.—Professor Rubens has shown¹ that the emissive power of the Welsbach mantle is in general very low. For the longer wave-lengths of invisible quality it has not so much as 1 per cent of the emissivity of an absolute black body. It has, for these rays, an emissivity even less than that of the Bunsen flame itself. But for light of the wave-length of 100 micro-centimetres or less, its emissivity, though less than that of an absolute black body, is far greater than that of the Bunsen flame. In the energy-spectrum of a Welsbach burner with mantles of different composition (Fig. 18) various maxima occurred. If pure oxide of iron or pure ceria

¹ See *Drude's Annalen*, vol. xx. p. 593.

were used, there was a maximum at about 200 microcentimetres. The flame also itself gave two maxima, one at about 260 due to water-vapour, and another at 430 due to the emissivity of carbonic acid. The energy-

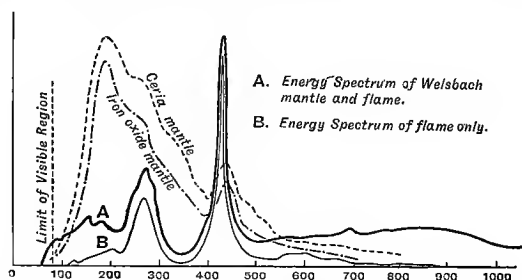


Fig. 18.—RUBENS' CURVES, ENERGY-SPECTRA OF RADIATIONS FROM INCANDESCENT GAS-FLAMES WITH VARIOUS MANTLES.

spectrum of the ordinary mantle itself (Fig. 19) showed two maxima, one for a wave-length of 120 microcentimeters, the other at about 900. The former showed that though the temperature was only about 1590°C . (*i.e.*

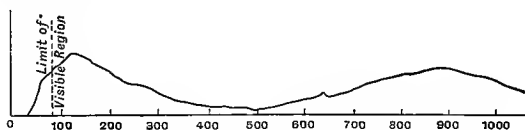


Fig. 19.—RUBENS' CURVE FOR EMISSIVITY OF WELSBACK MANTLE.

1863° , absolute), the quality of the light more nearly corresponded to that from a black body at 2450° , absolute.

High-pressure Incandescent Gas-lighting. — A still further advance has been made of late in the use

of high-pressure gas-burners. The usual pressure at which gas is supplied to our houses is quite low—about equal to the pressure of a column of water 2 to $2\frac{1}{2}$ inches high. But if the gas is compressed to a pressure of 40 or 50 inches of water, and supplied under that pressure to appropriate atmospheric burners, it mixes

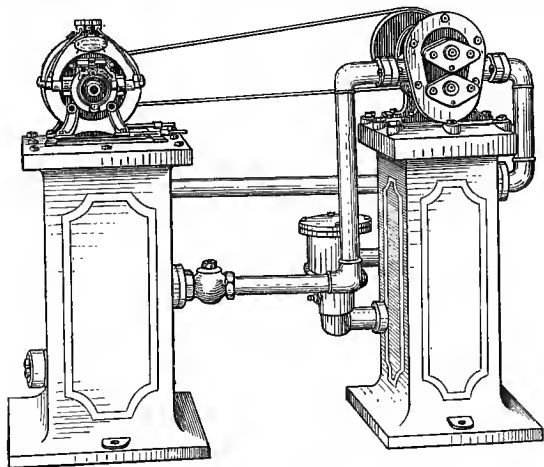


Fig. 20.—COLONIA GAS COMPRESSOR FOR HIGH-PRESSURE INCANDESCENT GAS-LIGHTING.

still more completely with the air, the temperature of combustion is raised still higher, and a still greater luminosity of the mantle results. It is this kind of incandescent gas-light which is rapidly coming into favour for lighting of squares and streets. And no wonder. Professor Wedding's tests on the high-pressure "Millennium light" show 1320 candle-power horizontally, or 933 candle-power spherically, with a consumption of 25 cubic

feet per hour of normal gas. If this had been burned in batswing burners it would have given only about 75 candle-power in total.

One objection to high-pressure gas-lighting is the trouble of the compressor to compress the gas mechanically. This can be done by any small motor. The "Colonia" compressor, Fig. 20, kindly exhibited by Mr. Blakey, is an example. The motor in this case is a small electric motor of $\frac{1}{2}$ horse-power. Mr. Blakey has also brought for exhibition a new automatic hydraulic compressor¹ of simple and ingenious design. It does not matter whether the gas is compressed, or whether we compress air and blow it into the gas-burner. Certainly the latter course seems preferable.

Mr. D. Anderson has kindly supplied an example of the Scott-Snell burner in which the compression of the air is effected by a small hot-air engine cunningly placed in the top of the lantern, and worked by the waste heat, so that each lamp is self-contained. Fig. 21 shows a section of the arrangement.

Great as has been the advance in gas-lighting, it is certain that the last word has not been said, and that abundant room exists for further improvements. The great economies effected by the use of high pressures apply only to burners of high candle-power. No one has yet invented an equally economic gas-burner for a small light of, say, 20 candle-power. For lights of 5 to

¹ The details of construction of this new compressor I am not at liberty to disclose. It is remarkably small and inexpensive, and the consumption of water, taken from the ordinary town mains, is very small.

20 candle-power the old, uneconomical flat-flame jet still remains. And against gas-lighting in domestic use there still remains the hygienic objection that all

gas-lighting poisons the air with carbonic acid gas, the product of combustion. With the economic significance of the modern gas-lights we shall deal presently.

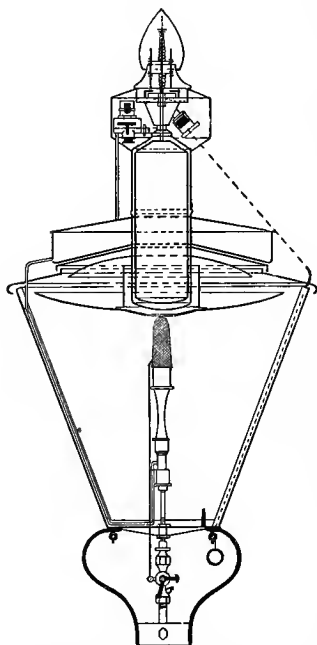


Fig. 21.—SCOTT-SNELL SELF-CONTAINED HIGH-PRESSURE GAS LAMP.

Efficiency of Glow-lamps.—We are now in a position to discuss the case of electric glow-lamps. The ordinary glow-lamp of commerce, with its filament of thin black carbon, as generally used, takes approximately 3 to $3\frac{1}{2}$ watts (spherical) per candle-power, and has a life of 1000 hours on the average, during which, however, owing to blackening of the bulb, its efficiency goes

down by some 20 to 40 per cent, the consumption increasing to 4 or $4\frac{1}{2}$ watts per candle. Fig. 22 gives the result of a test on twenty-four lamps at the National Physical Laboratory. The temperature of the filament may be taken as about 2000° (absolute). As is well

known, if the lamp is subjected to a higher voltage than that for which it is designed it will give out much more light, but its life will be short. Increasing the voltage causes more current to go through it; and when more

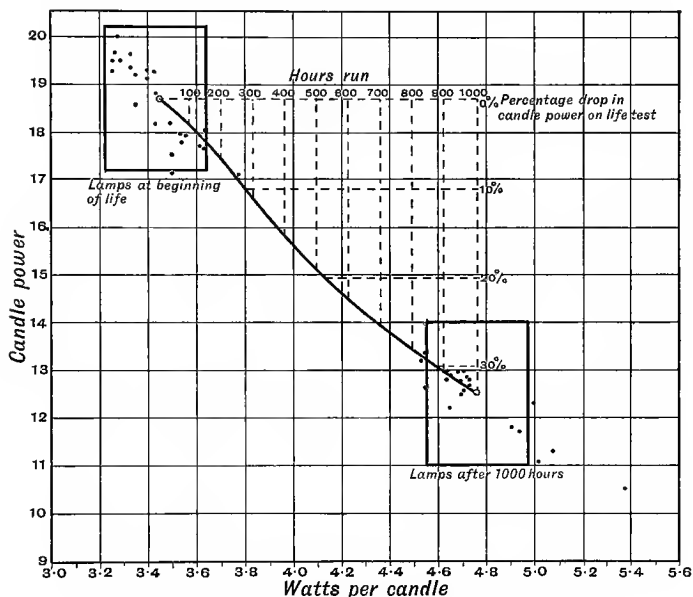


Fig. 22.—TEST-CHART OF TWENTY-FOUR ELECTRIC GLOW-LAMPS.

current is forced through it it gets hotter, and with the rise in temperature it emits more light and a whiter light.

A simple experiment will point the moral. Here is a glow-lamp designed to give 50 candle-power at 50 volts. By raising the electric pressure its light goes up; we

reach 70 candles, 100 candles, 150 candles, 200 candles. If we could only double the temperature before the filament breaks down we might theoretically reach 10,000 candle-power. But long before this the end comes, for at this high temperature the carbon in the filament

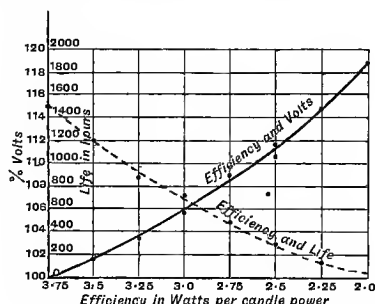


Fig. 23.—CURVE OF RELATION BETWEEN EFFICIENCY AND LIFE OF CARBON FILAMENT GLOW-LAMPS.

quickly disintegrates, and it breaks at the weakest point. Fig. 23 gives, from the experience of the Robertson Lamp Company, a diagram of the way in which, as we raise the volts, we raise the efficiency, but also shorten the life of the lamp. The life-factor may be conveniently stated in the following form :—

Per Cent of Normal Voltage.	Per Centage of Normal Life.
100	100
101	80.8
102	68.1
103	56.2
104	45.2
105	37.4
106	31.0

Raising the voltage only 6 per cent reduces the average life to less than one-third of the normal value.

New Kinds of Glow-lamps.—Several newer kinds of glow-lamps are now in the market. A radical departure was made some seven years ago, when Nernst proposed to use a filament that looks like a thread of pipe-clay, but is in reality made of zirconia and yttria, or similar materials of special emissivity. Such a thread does not conduct the electric-current unless first heated; so the Nernst-lamps, Fig. 24, contain a special heating device warmed by the current itself, so that the filament lights up as soon as it becomes conductive. Partly because of the specific emissivity of the materials, also probably, in part, because of the attainment of a higher temperature, the Nernst filament works with a higher efficiency than the carbon filament, requiring only about 2 to $2\frac{1}{4}$ watts per candle. The dominant wave-length of its light is 128 millionths of a centimetre, which would correspond to a temperature of 2300° (absolute), if it radiates as a black body does. If the effect is due to a specific emissivity the actual temperature may be lower.

More recently glow-lamps have been proposed having metallic filaments. Platinum will not do for this purpose; its melting point (1775° C.) is too low. But the rare metal osmium has been proposed by Auer von Welsbach, tantalum by von Bolton and Feuerlein, zirconium by Zerning, and tungsten by Kusel. The difficulty in preparing fine wires, about $\frac{1}{500}$ inch thick, of these hard and almost infusible metals is great but not insurmountable. Osmium-lamps have been on the market for over two years, tantalum-lamps for about a twelvemonth.

Tungsten-lamps are not yet in commerce. Yet the results have been most promising, and the tantalum-lamp (Fig. 25) is already largely in demand. With the osmium-lamp the consumption of energy goes down to 1.76 watts per candle; with the tantalum-lamp to 1.5

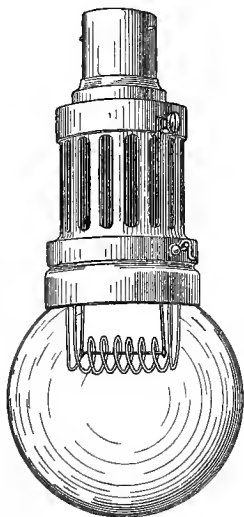


Fig. 24.—NERNST GLOW-LAMP.

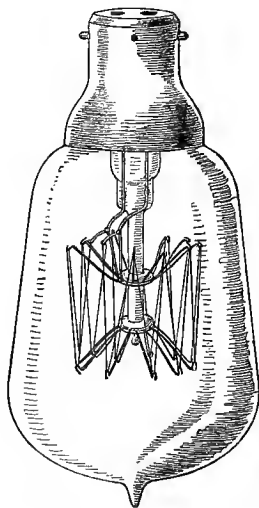


Fig. 25.—TANTALUM-LAMP.

watts per candle. The melting point of tantalum is about 2520° or 2570° (absolute); hence the light is very white. For the tungsten-lamp an efficiency of 1 candle per watt is claimed. If this is true, the cost of electric-lighting will be reduced to one-third of that of our present carbon glow-lamps. Here, at least, is attainable a considerable economy in the manufacture of light.

New kinds of Arc-lamps. — Improvements in electric arc-lamps are also to be noted. The ordinary arc-lamp sheds its light mainly from the white-hot end of the upper carbon rod ; but as the lower carbon comes

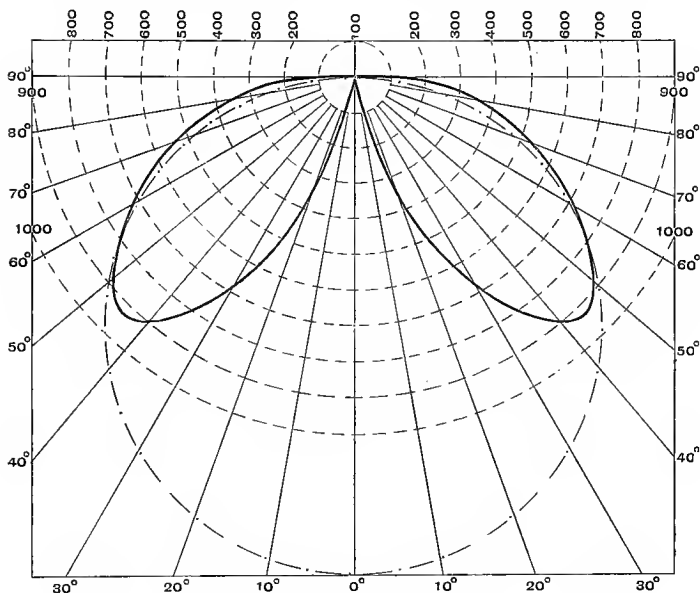


Fig. 26.—CURVE OF DISTRIBUTION OF LIGHT OF ORDINARY ARC-LAMP.

into the way, the maximum illumination is cast obliquely downward, as the curve of distribution of light, Fig. 26, shows. About twelve years ago the fashion began of enclosing the arc in a nearly air-tight inner globe. By this device the rate of consumption of the carbon rods was greatly reduced, thereby saving much of the cost

and labour of renewals. But the loss in light by absorption due to the double globe was very considerable, and the efficiency of the lamp reduced. More recently an advance has been made in the introduction of impregnated carbons. Salts of potash have long been known to improve the quality of the light emitted; and, moreover, their introduction permits a wider separation of the

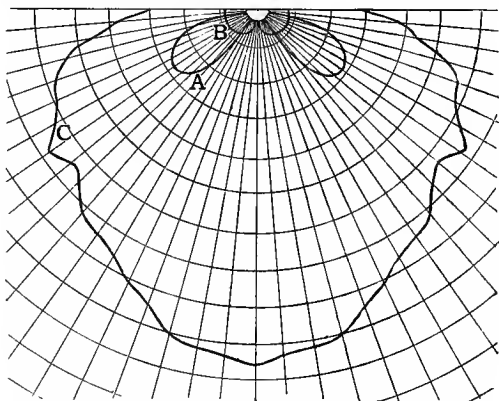


Fig. 27.—CURVES OF DISTRIBUTION OF LIGHT OF ARC-LAMPS.

carbons, so that the downward light is less intercepted. Salts of strontium and calcium, particularly the fluoride of calcium, are effective in increasing the quantity of light emitted for a given consumption of energy. In these cases the arc becomes a veritable flame of light, the luminosity being mainly in the arc itself and no longer in the incandescent tips. By using two inclined carbons with arc deflected downward, an enormous increase in light is obtained. The curves of Fig. 27 (due to Wed-

ding) are instructive. That marked A is the distribution curve of an ordinary "open" arc-lamp. When surrounded by an interior globe as an "enclosed" arc, the output is diminished to the value shown by B; while, when a "flaming" arc was produced, using only the same amount of energy, the output of light was increased more than fourfold, and the distribution curve takes the form delineated in C. The introduction of salts of calcium gives to the arc a fine orange hue, which appears to possess special penetrative powers in a foggy atmosphere. By the kindness of the Union Electric Company of London, one of their "Excello" flaming arc-lamps is here exhibited.

The Magnetite Arc-lamp.—The newest species of arc-lamp is that of Dr. C. P. Steinmetz of Schenectady. After careful study of incandescent materials, he selected the oxide of iron, called *magnetite*, for making the negative electrode of the lamp. This material, mixed with the oxide of chromium or of titanium, rammed into an iron cartridge, is supported at the bottom of the lamp. The upper or positive pole is a piece of solid copper. The arc thus produced is an intensely white column of light about 1 inch long. The copper pole is not consumed, and the cartridge of magnetite is only slowly used up. One feature of this lamp is that the maximum of the light is thrown almost horizontally, so that it is admirably adapted for the lighting of streets. This lamp, not being yet in the market in this country, I am indebted to Dr. Steinmetz for the specimen now shown. It is highly efficient, giving about twice as much light as the ordinary arc-lamp for equal consumption of energy. The spec-

trum of the light of the magnetite arc reveals the cause of this high efficiency. It consists largely of brilliant bands of light in the green and red regions; in fact, it is largely a gaseous spectrum.

The Electric Vapour-lamp.—The vapour of mercury, traversed by an electric current, emits a brilliant bluish-green light. Various lamps have been designed to bring this into practical use. Of these the best known is the Cooper-Hewitt. The British Westinghouse Company has kindly supplied two of these for this lecture.

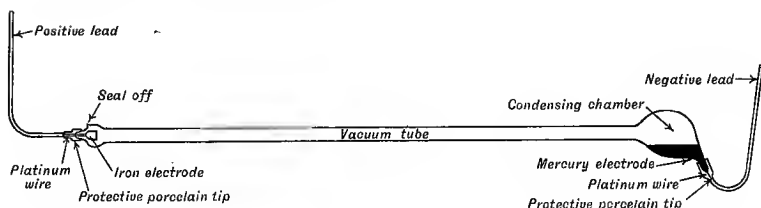


Fig. 28.—COOPER-HEWITT MERCURY VAPOUR-LAMP.

A glass tube, about 1 inch in diameter, and 3 or 4 feet in length, according to the voltage of supply, is arranged with suitable electrodes at the ends (Fig. 28), and contains nothing else except mercury and mercury vapour. To cause the current to flow it is sufficient to tilt the lamp, causing the thread of mercury that is formed along the bottom of the tube when horizontal to part. At once the tube is filled with a soft but brilliant flood of green light. It is found to be about the same efficiency as the ordinary arc-lamp, giving about 1.66 candles per watt, and is therefore far above any of the glow-lamps in its economy.

As already pointed out, it is the property of a vapour, when incandescent, to throw its energy into a few brilliant rays, producing in this case a predominance of green and blue. The heat-rays are not absent : but there is a higher proportion of luminous rays than would be the case if the shining body were a solid. Vapour-lamps may therefore be regarded as a step towards the luminescence lamp of the future. If only one could devise a plan of setting the atoms or electrons into vibration without exciting the grosser vibrations of the molecules the end would be attained, and the very freedom of the molecules in the gaseous state seems to favour this possibility. Yet in the phosphorescence of the fire-fly, and in the luminescence produced by cathode discharges, there appears to be a possibility of touching the atom within the molecule, even in substances that are not vapours.

Comparison of Electric-lamps. — The following table exhibits in comparative form the efficiencies of the

EFFICIENCIES OF ELECTRIC-LAMPS

	Watts per Candle.	Candles per Watt.	Candles per H.P.
Glow-lamp . . .	3.3	0.3	246
Nernst-lamp . . .	1.5	0.67	495
Osmium-lamp . . .	1.5	0.67	495
Tantalum-lamp . . .	1.4	0.7	532
Tungsten-lamp . . .	1.0	1.0	746
Arc-lamp . . .	0.67	1.5	1110
Vapour-lamp . . .	0.6	1.66	1240
Magnetite-lamp . . .	0.25	4.0	2984
Flame Arc-lamp . . .	0.17	5.8	4300

various kinds of electric lamps, and shows how great is the advance made by the recent inventions. The great economy of the flame arc is, however, not sustained except for arcs of enormous power; and a small lamp, that is, one of from 5 to 20 candle-power, giving more than 1 candle-power per watt is a thing still awaiting invention.

Cost of Manufacture of Light.—We come now to the all-important question of the cost of the light as manufactured in these different kinds of lamps. To deal with this question we must adopt some figures for the cost of the gas, the oil, and the electric-energy which are respectively the supplies from which the light is manufactured. Prices differ in different districts. Those taken here for convenience are—

Gas (normal 'quality 16-candle' gas at 5 cubic feet per hour) taken at 2s. per 1000 cubic feet.

Paraffin Oil (American kerosene, with flash-point at 110° F.) taken at 8d. per gallon.

Electric-Energy taken at 2.4d. per "unit" (*i.e.* per kilowatt-hour).

One must also adopt a unit for quantity of light, and for this we take the *candle-hour*, meaning the total quantity of light given out during 1 hour by a light of 1 candle-power.

The following table gives a résumé, according to the measurements of Professor Wedding, translated into British values, of a number of different sources of light as measured by him. For these the figures of cost given are calculated down into pence per candle-hour

on the foregoing basis. In a city like York, where gas costs 1s. 10d. instead of 2s. per 1000 cubic feet, the cost of gas-lights will be reduced correspondingly. In London, where the price is 2s. 9d., they will be correspondingly raised.

COMPARISON OF SOURCES OF LIGHT (after Prof. W. Wedding).

Prices taken : Gas at 2s. per 1000 cubic feet ; Oil at 8d. per gallon ; Electric-energy at 2.4 pence per unit.

	LIGHT.		WATTS.	EFFICIENCY.			COST.		POISON.		
	Candle Power.			Watts per Candle.	B. Th. U. per Candle-hour.	Luminous Efficiency.	Pence per Candle-hour.	Pence per 1000 Candle-hours.	Candle-hours for 2 shillings.	Cubic inches of CO ₂ .	
	Horizontal.	Spherical.								Total per Hour.	Per candle-hour.
Gas (Batswing)	16	13.6	1440	106	310	0.00015	0.00882	8.82	2,720	7,590	536
Paraffin-lamp	13	11.6	560	48.2	146	0.00029	0.00304	3.04	7,895	4,276	366
Welsbach Mantle.	65	46.0	670	14.5	43	0.00018	0.00192	1.92	12,500	3,600	72.5
Millennium-light	1320	933	7140	7.65	22.7	0.00081	0.00094	0.94	25,494	38,400	39
Glow-lamp No. 1	38.6	30.5	104	3.4	10.02	0.00066	0.00641	6.41	3,745	...	...
„ „ No. 2	16.1	11.5	59.1	5.24	15.5	0.00335	0.00992	9.92	2,419	...	...
Osmium-lamp	37.3	27.6	48.7	1.76	5.22	0.00622	0.00336	3.36	7,143	...	...
Nernst-lamp	162.1	99.5	213	2.13	6.32	0.00850	0.00408	4.08	5,882	...	...
Arc-lamp (ordinary)	...	352	440	1.25	3.71	0.00318	0.00240	2.40	10,000	653	2.2
Flame Arc	...	1655	440	0.265	0.78	0.01080	0.00050	0.504	47,619	1,306	0.8

If we cast our eye upon the column of figures headed *British Thermal Units per Candle-hour* we find there how vastly the different sorts of lamps differ in the amounts of heat-energy which has to be supplied to them to generate equal total amounts of light. While the batwing gas-jet needs 310 British thermal units¹ to give 1 candle-hour, an electric flaming arc needs less than 1 B.T.U. per candle-hour. Again, an incandescent gas-light of ordinary Welsbach mantle type requires 43 B.T.U. per candle hour, whilst an ordinary glow-lamp only requires from 10 to 15 B.T.U. per candle-hour. Yet it is notorious that the incandescent gas is cheaper than the glow-lamp for equal amounts of light. The explanation lies in the difference in the cost of the heat; for the incandescent gas-light gets its heat by burning gas, whereas the glow-lamp gets its heat from the electric-energy supplied to it. And (at the prices taken) a B.T.U., if manufactured by burning gas, costs 0.000042 pence, whilst if manufactured by expenditure of electric-energy costs 0.00064. That is to say, so far as production of the mere heat in the lamp is concerned, electricity (at the prices taken) costs fifteen times as much as gas. But heat is precisely what we do not want. And because the gas-lamps waste so much of their energy in mere non-luminous heat, they are not, when we come to examine the column of figures of costs

¹ The *British thermal unit* is that amount of heat which would warm 1 pound of water 1 degree of the Fahrenheit scale. It is equal to 251.98 *gramme-calories*, or to 1048 joules, or to 0.000296 *kilowatt-hours*. One *kilowatt-hour* equals 3435 British thermal units.

per candle-hour, so superior. How much light can we buy for a florin? That question is answered in the figures of the table. The dearest source, except a bad glow-lamp (No. 2, which was obviously very inefficient even for a glow-lamp), is the batswing gas-jet, which gives for a florin only 2720 candle-hours. The best of the gas-lights is the high-pressure incandescent, represented in the Table by the Millennium, which gives 25,494, but it is surpassed by the Flame Arc, which gives 47,619.

The Cheapest Form of Light.—Earlier our attention was drawn to the circumstance that the process of manufacturing light by *incandescence* was indirect, while the process of manufacture by *luminescence* was direct, the energy being turned into light without the production of extraneous heat. This is the secret of the glow-worm and the fire-fly; but it is also the secret of the more brilliant phosphorescence of the cathode rays, as shown you in Crookes' vacuum tubes. Somehow these insects have found out the way, which man also has found in the case of the Crookes' tubes, how to excite the delicate vibrations of the atoms, or of the electrons associated with them, without having to resort to the coarser process of setting all the molecules of the mass dancing with heat. In the possibility of chemical or cathodic means of exciting luminescence lie the immense opportunities of the future. We in Great Britain spend annually a gigantic sum, estimated at from £10,000,000 to £20,000,000 in manufacturing for ourselves such artificial lights as our civilisation demands. Ninety-nine per cent at least of this colossal

sum is thrown away on mere heat. What a future awaits the man who will invent a practicable *luminescence lamp* giving light without heat !

Future Progress.—It is abundantly evident that there is room for future developments. Progress comes about in two ways. We may take the existing things and by careful experiment and attention to detail improve them bit by bit : that is one way. But every now and then it happens that a man of genius working in the quiet of his laboratory discovers some new fact, which is at first apparently obscure and of no importance. He publishes the observation by reading a paper to some learned society : it is printed in its journal of proceedings and promptly forgotten. Years afterwards, it may be, some practical man comes along, gets hold of the obscure fact, and works it up into a shape that has commercial value. He gets hold of a financier who puts it on the market, and the world hears of a new invention. Somebody makes a fortune, but very seldom does it benefit the original discoverer. The special incandescence of erbia and thoria was known to the chemists forty years ago ; but no one heard of incandescent gas-lighting till Auer von Welsbach devised the mantle to utilize this remarkable property. I have shown you the remarkable luminescence of rubies and of willemite when stimulated by cathode discharges in a Crookes' tube ; but luminous-lamps on that plan are not yet practical.

The great economies effected by high-pressure gas and by the flame arc are as yet only attained in big lamps. The immediate want is the production of small lamps of equal economy. Perhaps we shall have small electric

vapour-lamps before long. One step toward improvement will be the cheapening of the sources of supply, both of gas and of electric-energy. Gas ought now to be evaluated not by its supposed candle-power, but by its calorific power. A gas equal in heating-power to that now supplied could be made for 10 pence per cubic foot if we did not require it to burn with a bright flame of its own, and were to use mantles to get the light. And electric-energy instead of costing 2.4 pence per unit can be manufactured at far less than $\frac{1}{2}$ penny per unit, if manufactured on a large enough scale. There are tremendous possibilities before us: but the possibilities before us in the domain of luminescence are far greater than those in the domain of incandescence. I have no fear as to the ultimate solution of the problem of the manufacture of light. The lamp of the future giving light without extraneous heat will be a luminescence lamp. It will therefore be an electric-lamp, but not an incandescent one.

A Radium - lamp.—To the possibilities already named, science has lately added a new one in the discovery of radium. This surprising and perplexing metal acts as though it were an inexhaustible source of invisible radiations of singular power. A few milligrammes of radium placed near a piece of phosphorescent material such as willemite, cause it to shine in the dark, making thus a perpetual lamp. You may think that here we have the promise of the very cheapest source of light. Alas for such wishes, the laws of economy are not yet to be over-ridden. Radium is excessively rare and expensive. To produce by its phosphoric stimulus on willemite

a lamp of even 1 candle-power requires a few milligrammes of radium, and those few milligrammes will cost at least £40. For a capital cost of £40 one may get a perpetual light of 1 candle-power! And the mere interest on the capital will run to something like one farthing per hour for all the hours that the light would be of service. Why, a tallow candle would be cheaper. The dearest of all our sources of light by incandescence does not run to more than $\frac{1}{100}$ th of a penny per candle-hour. So that which seemed to be the cheapest source of light, costing nothing but interest on capital, turns out to be the dearest.

Sunlight after all.—No, the cheapest source of light still remains to be the commonest and most universal, the light of the sun, which shines alike on rich and poor, and gives us—such is the admirable economy—a light of which the dominant wave-length is 50 millionths of a centimetre, just that wave-length to which our eyes have become, in the long evolution of the ages, the most sensitive. By no artificial process can we manufacture light so cheaply that it would not be still cheaper to adjust our social habits to the hours of sunlight, and do our day's work while it is yet day.

THE END

1/- NET